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M.L. Meeks

VHF Propagation Near the Ground: An Initial Study

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LEXINGTON, MASSACHUSETTS

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FOR THE COMMANDER

Thomas J. Alpert, Major, USAF
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

VHF PROPAGATION NEAR THE GROUND: AN INITIAL STUDY

M.L. MEEKS
Group 48

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ABSTRACT

This report describes an initial investigation of propagation near the ground in forested terrain at a frequency of 110.6 MHz. The objective was to study propagation effects that influence the illumination of ground-clutter targets by a ground-based radar. We used as a transmitter an aircraft-navigation aid, the VHF omnidirectional range at Gardner, Massachusetts. Ground-based measurements of signal strength at heights from 2 to 15 ft above the ground were made at two locations, 2.2 and 8.8 miles away, and the field strengths corresponding to free-space propagation at each location were measured with a helicopter hovering over the site of the ground-based measurements at sufficient altitude to avoid terrain-diffraction effects. The results of the ground-based measurements are compared with calculations that model the propagation effects on the basis of terrain profiles determined directly from relief maps with corrections for tree height. The model took into account diffraction by masking hills. In addition specular reflection from the open fields immediately in front of the receiving antenna at both sites was found to produce the steep gradients in field strength observed below a height of 10 ft above ground.

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1.0 Introduction

In December 1980 we made ground-based measurements to investigate the influence of VHF propagation effects on ground clutter. These measurements were made using as a signal source an aircraft-navigation aid, a VOR (for VHF Omnidirectional Range) located near Gardner, Massachusetts. Helicopter measurements were also made in order to reference the signal-level measurements near the ground to the free-space signal level. To model the results of these measurements, we used a multiple-diffraction computation to take into account terrain masking, and we used the method of images to account for specular ground-reflections immediately in front of the receiving antenna. Although these measurements and the modeling computations represent a preliminary investigation of the problem, the results suggest that considerable insight into ground-clutter behavior could be obtained by more extensive measurements of this type.

2.0 Description of the Measurements

The field-strength measurements were made with a Singermetrics 37/57 EMI field-intensity meter which was used in the helicopter measurements reported by Meeks[1]. This instrument is battery powered and could be carried to the sites of the ground-based measurements. The receiving antenna on the ground was a standard-gain dipole which could be moved

up and down a vertical 16-ft pole made of 2½-in diameter PVC pipe. This dipole could also be moved along a 10-ft horizontal pole of the same material to sample the field as a function of horizontal position at a height of 7 ft. The field strength was measured at intervals of 2 ft along the poles, and the values were recorded manually. We were careful to see that the investigators stood well clear of the dipole antenna when the measurements were made so that reflections from their bodies did not distort the field. Figure 1 shows the vertical pole with the dipole attached, and Fig. 2 shows the horizontal pole and dipole antenna.

The transmitter used for these experiments was the Gardner VOR operating at a frequency of 110.6 MHz. The radiation was horizontally polarized and the transmitting-antenna pattern was symmetric in azimuth. Variations in antenna gain due to the very small changes in elevation angle were neglected.

We made measurements at two sites: (1) the south end of the Gardner airport (distance 2.2 mi) and (2) a hilltop east of Round Meadow Pond (distance 8.8 mi). Figure 3 shows a photograph at the airport site looking toward the transmitter, and Fig. 4 shows a view looking toward the transmitter from the hilltop site. At both locations the line of sight to the transmitting antenna is masked at low altitudes. In Fig. 3 a

Fig. 1. The Receiving Antenna Mounted on the Vertical Pole.

Fig. 2. The Receiving Antenna Mounted on the Horizontal Pole.

Fig. 3. View from the Gardner Airport Site Looking Toward the Transmitter.

Fig. 4. View from the Round Meadow Site Looking Toward the Transmitter.

masking ridge lies out of sight behind the trees, and in Fig. 4 a masking ridge is visible through a row of trees in the foreground. In both photographs the direction toward the transmitter lies at the center of the horizontal pole. The measurements were made when the deciduous trees had lost their leaves as the photographs show.

We calibrated the ground-based measurements relative to free-space propagation by using a helicopter to measure the field strength directly above the two ground sites at altitudes sufficiently high to avoid terrain-diffraction effects. Specular reflection from the terrain was not expected based on previous experiments with the Gardner VOR, reported by Meeks[1]. The vertical descents made over each site showed no evidence of lobe structure. The gain variation with elevation angle of the transmitting antenna is less than 2 dB for the elevation intervals involved in the helicopter measurements as determined from VOR antenna patterns reported by Sengupta[2].

3.0 Analysis of the Data

Figure 5 shows the results of measurements made at the south end of the Gardner airport runway. The signal strength (dBm) is plotted vs height above ground (ft). Based on the helicopter measurements, the signal strength for free-space

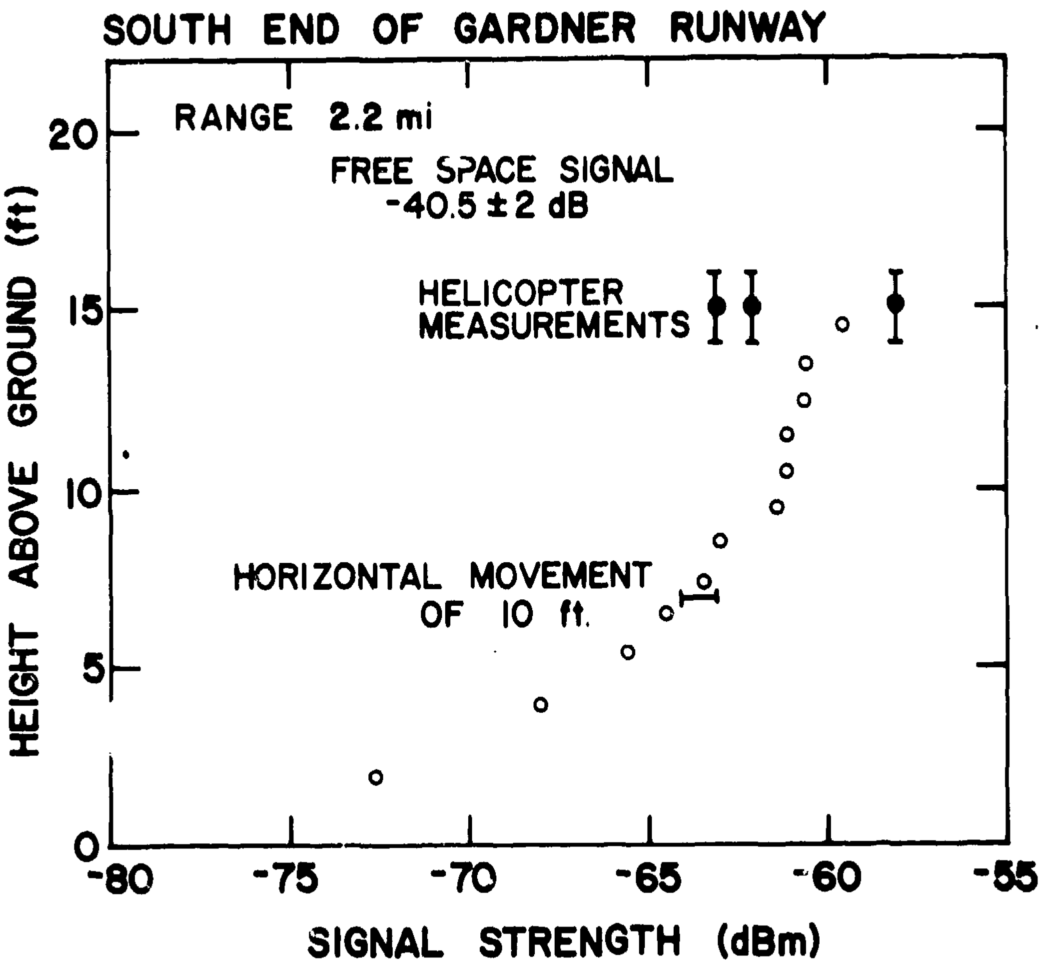

Fig. 5. Measurements at the Gardner Airport Site.

propagation over the distance to the measurement site (2.2 mi) is -40.5 ±2 dBm, based on measurements made at the beginning of three helicopter descents. Also the helicopter carrying the receiving antenna hovered near the top of the pole used for the ground measurement at the end of each descent. The spread of these three measurements near the top of the pole is 5 dB and the agreement with ground-based measurements is satisfactory as shown in Fig. 5. The ground-based measurements are plotted as points in Fig. 5. With the antenna attached at the top of the pole, 15 ft above ground, the signal strength was 19 dB below the free-space signal strength. As the antenna moved down below about 10 ft above ground, the signal strength dropped very rapidly, falling about 11 dB between 10 and 2 ft. The range of signal strengths measured when the antenna was moved along the horizontal pole is also shown in Fig. 5. Little variability was found when the receiving antenna was moved 10 ft horizontally at a height of 7 ft; the signal varied by no more than 1 dB.

Figure 6 shows the results of measurements on the hilltop east of Round Meadows Pond. The helicopter measurements near the ground are less consistent at this site. The helicopter measurements gave an average signal strength at the top of the pole of -65 dBm as compared to -71 dBm for the ground-based measurements. A larger horizontal variability (2.5 dB) was

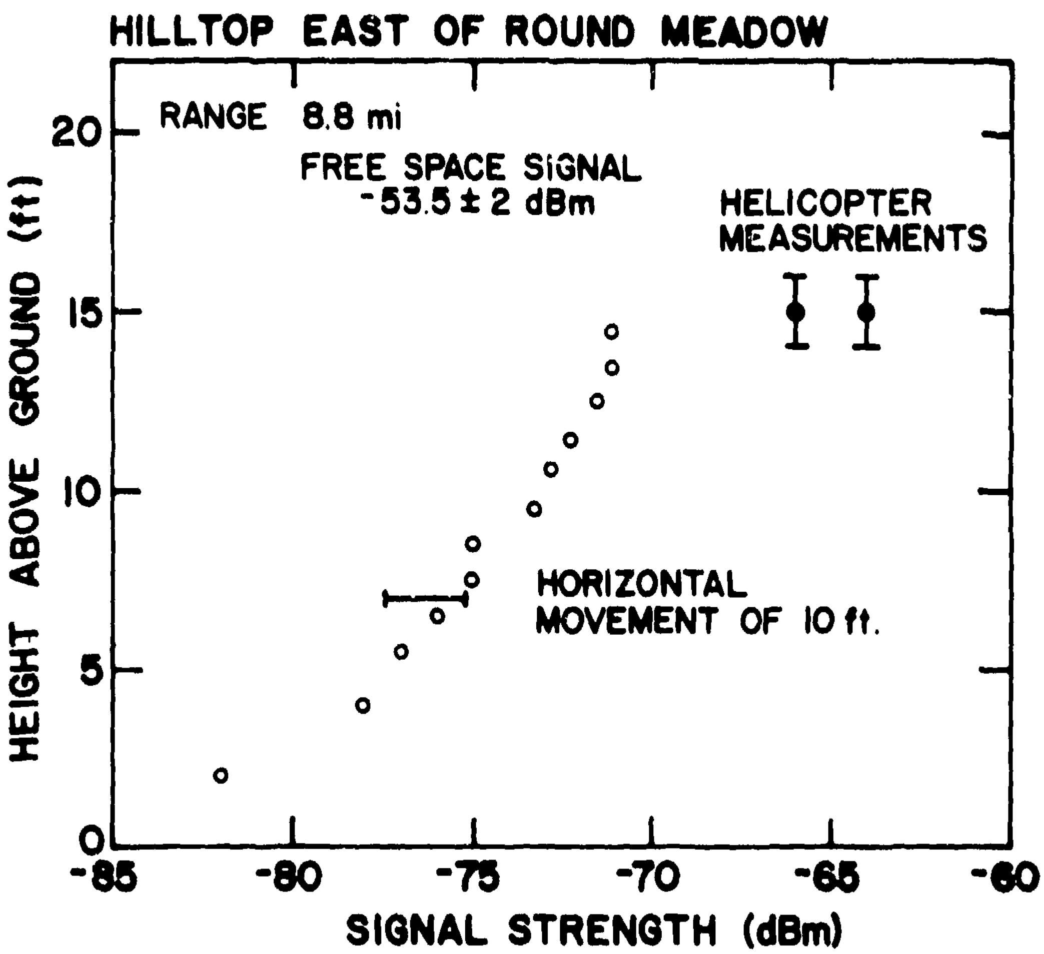

Fig. 6. Measurements at the Round Meadow Site.

found for 10 ft of horizontal motion, and this horizontal variability may help to explain the discrepancy between the helicopter and the ground-based measurements. At this site the signal was attenuated to some extent by the rows of trees shown in the foreground of Fig. 4. Again a very rapid decrease in signal strength was observed near the ground with the signal decreasing 11 dB between heights of 15 and 2 ft above ground.

Above the two sites the helicopter measurements of the signal strengths corresponding to free-space propagation, -40.5 and -53.5 dBm, differ by 13 dB. This result is in good agreement with the predicted -12.1-dB difference expected for propagation over 8.8 mi as compared to 2.2 mi based on the R^{-2} dependence of free-space propagation, where R is the distance.

4.0 Comparison with Propagation Models

It is important to determine whether the ground-based measurements can be fit with a propagation model. The extent to which the results of these measurements can be understood and generalized will depend on how well the behavior of the data can be explained by a propagation model. Earlier helicopter measurements over six propagation paths from the Gardner VOR were reported by Meeks[1]. In these experiments the helicopter measured the signal strength during vertical descents from 2000 to 50 ft above ground at distances between

4.4 to 9.3 miles from the VOR. A multiple-diffraction model was developed to fit these data. The model, which is described by Meeks[1], fits the measurements well when the excess propagation loss is computed by selecting the two most prominent masks on the terrain profile, treating these masks as knife-edges, and computing the double-knife-edge loss by means of the Deygout approximation[3]. This model assumes that specular reflection from the ground is negligible. However the steep gradient in the field strength observed in the ground-based measurements plotted in Figs. 5 and 6 would be difficult to explain by diffraction alone. However, both sets of ground-based measurements were made in the open fields. At Gardner airport the level ground extended from the antenna to the edge of the forest at a distance of 700 ft (see Fig. 3). On the hill east of Round Meadow Pond the open field sloped down at an angle of 6 degrees from the antenna location to the row of trees shown in Fig. 4, a distance of 180 ft. In both cases specular reflection from these open fields should evidently be taken into account in modeling the propagation.

To model the ground-based measurements we again used the Deygout approximation to describe the multiple diffraction, and also between the receiving antenna and the nearest knife-edge we represented the open field by a flat dielectric plane with the real part of the relative dielectric constant equal to 6.0 and the imaginary part equal to 0.45, the values

appropriate for soil with 10% moisture content by volume as reported by Njoku and Kong[4]. (For the low grazing angles involved in this geometry the magnitude of the reflection coefficient is effectively unity for horizontal polarization independent of moisture content or soil type as discussed by Meeks[5]). The method of images was used to take into account the reflecting plane as described by Meeks[6]. Although the open fields extend only part of the way between the ground-based antenna and the nearest knife-edge, the areas where the specular reflection occurs lie in the open fields for the geometry of these profiles.

Figure 7 shows the terrain profile for the measurements at Gardner airport. The two knife-edges used in the multiple-diffraction calculation are identified in this figure. Figure 8 shows the model calculations superimposed on the measured data plotted in Fig. 5. In Fig. 8 we have normalized the signal-strength measurements relative to free-space propagation as determined by helicopter measurements high enough above the ground to avoid diffraction effects. The agreement between the model predictions and the data is within ± 0.5 dB if we offset the predictions by 1.7 dB as indicated by the dashed line. The model thus accurately predicts the shape of the signal-strength measurements as determined by terrain reflection, but with a constant error of 1.7 dB. A dotted line in Fig. 8 shows the model predictions for diffraction

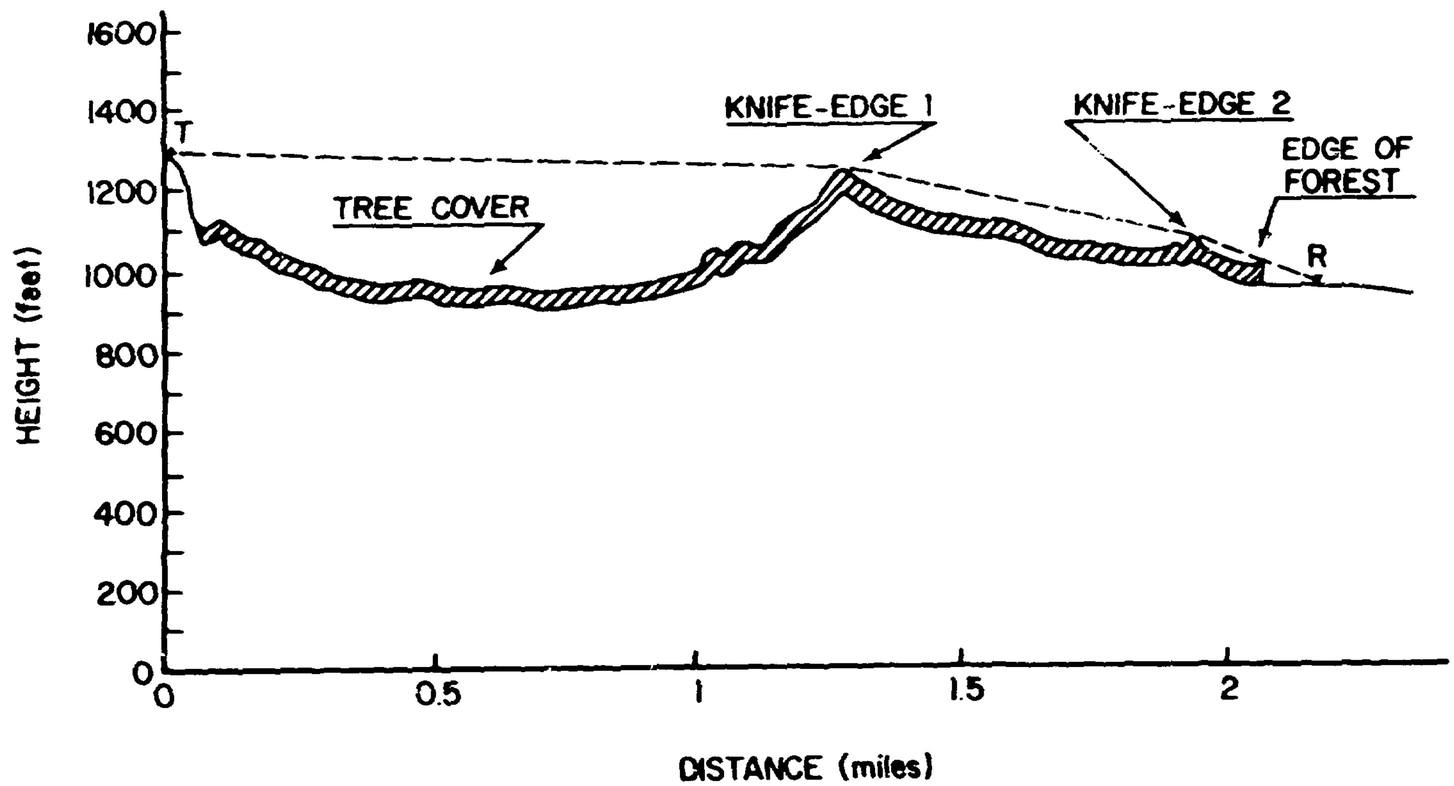

Fig. 7. The Terrain Profile Between the Gardner VOR and the Gardner Airport Site.

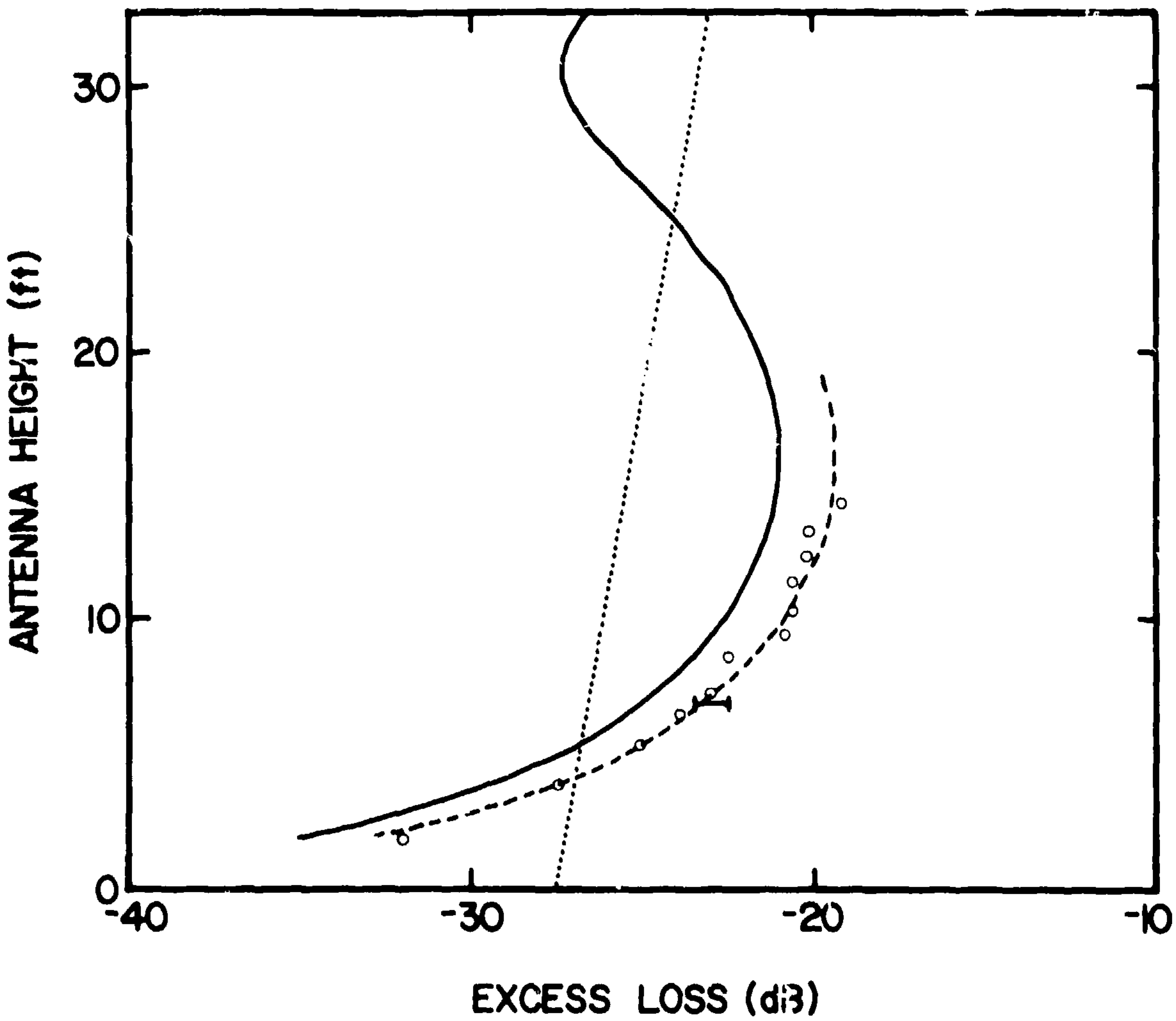

Fig. 8. Model Predictions of Excess Loss and Measurements at the Gardner Airport Site. The dashed line shows the prediction curve shifted by 1.7 dB. The dotted line shows the predictions for diffraction alone.

effects without specular reflection; the effect of reflection is to impose a lobe structure on this curve. The predicted diffraction loss is sensitive to the exact heights of the masks, and the constant error of 1.7 dB can easily be explained in this way. In fact the smallness of this constant error may be fortuitous. We have compared the Deygout calculation with the more exact multiple-diffraction computation of Vogler[7]. This computation for the two knife-edges identified in Fig. 7 agrees with the Deygout calculations to within 0.1 dB.

Note in Fig. 7 that the tree tops at the edge of the forest which we can see in Fig. 3 lie nearly on the line of sight between the receiving antenna and the second mask. Since we increased the heights of the masking ridges to include the tree heights, to be consistent we should take into account the diffraction effects of the trees at the edge of the forest. However it is not clear how the model should treat the edge of the forest which represents a step discontinuity from a rough surface (the tree tops in the forest) to a smooth surface (the flat cleared ground). If we consider the forest edge as a knife-edge and include it in the diffraction computation, the Vogler computation leads to a significantly larger constant error of 6.3 dB between the measurements and the model calculations. Hence the experimental results suggest that the forest edge should not

be considered as a knife-edge mask, nevertheless because of the sensitivity of the multiple-diffraction computations to the assumed heights of knife-edges 1 and 2, we cannot draw any general conclusions from this single experiment as to how to take into account forest edges.

Figure 9 shows the terrain profile for the measurements near Round Meadow Pond. Model computations for this path were also made with the Deygout approximation for two knife edges identified in Fig. 9. The sloping hillside was represented as a flat dielectric plane with the same slope as the hillside. We assumed the same electrical constants for the ground here and at Gardner airport. Figure 10 shows the model computations and the measurements plotted relative to free-space propagation as determined by helicopter measurements made at altitudes high enough to avoid diffraction effects. In this case the model predictions are one or two decibels stronger than the measurements at heights greater than 4 ft above ground. The row of trees in the foreground of Fig. 4 was not included in the diffraction computation, but we would expect that the measured signal would have been attenuated by passing through these trees. Uncertainties in this experiment prevent us from accurately determining this component of the propagation loss. The shape of the predicted curve in Fig. 10 is a result of ground reflection; the dotted line shows the model prediction based on diffraction alone. In this

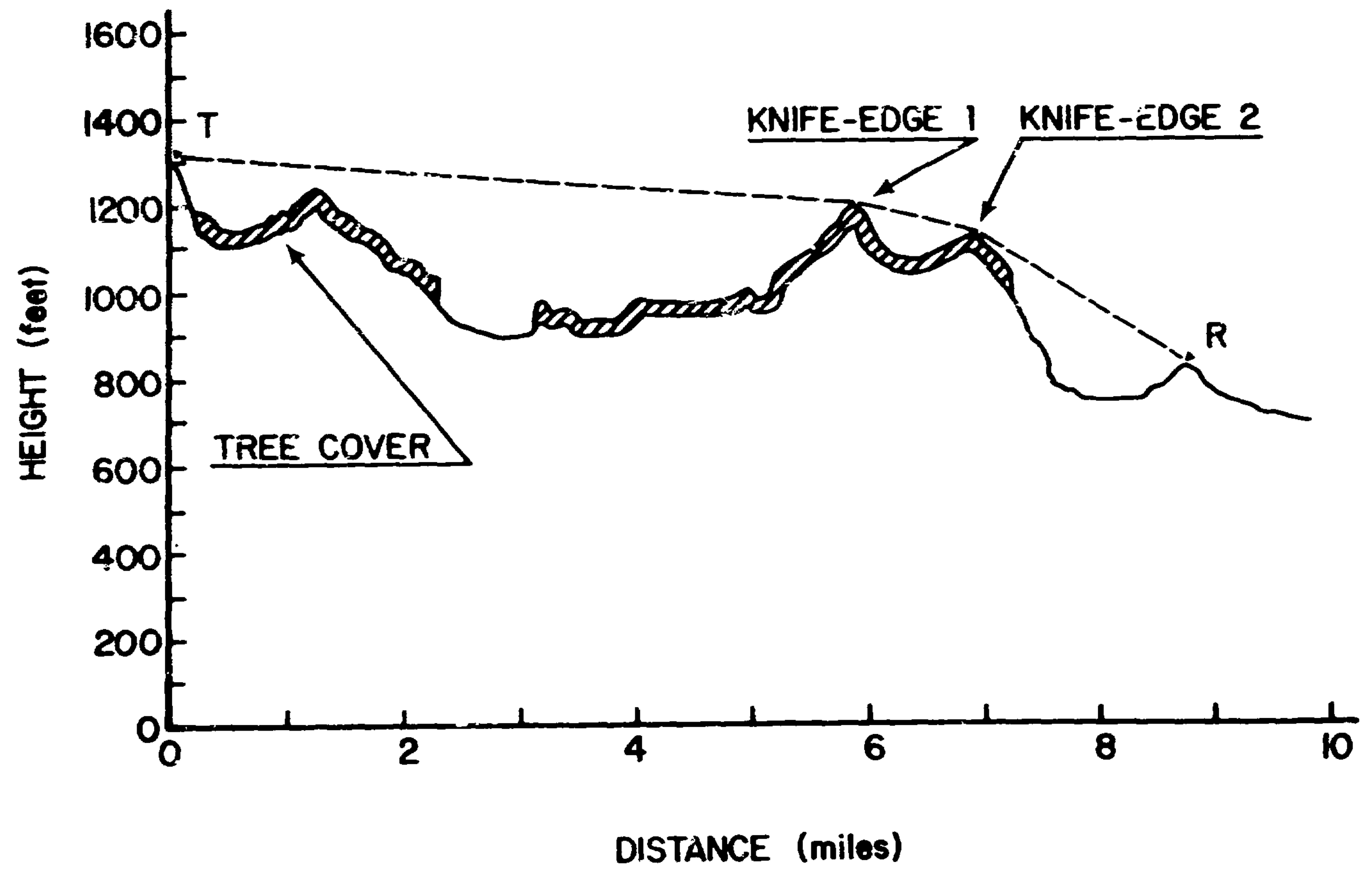

Fig. 9. The Terrain Profile Between the Gardner VOR and the Round Meadow Site.

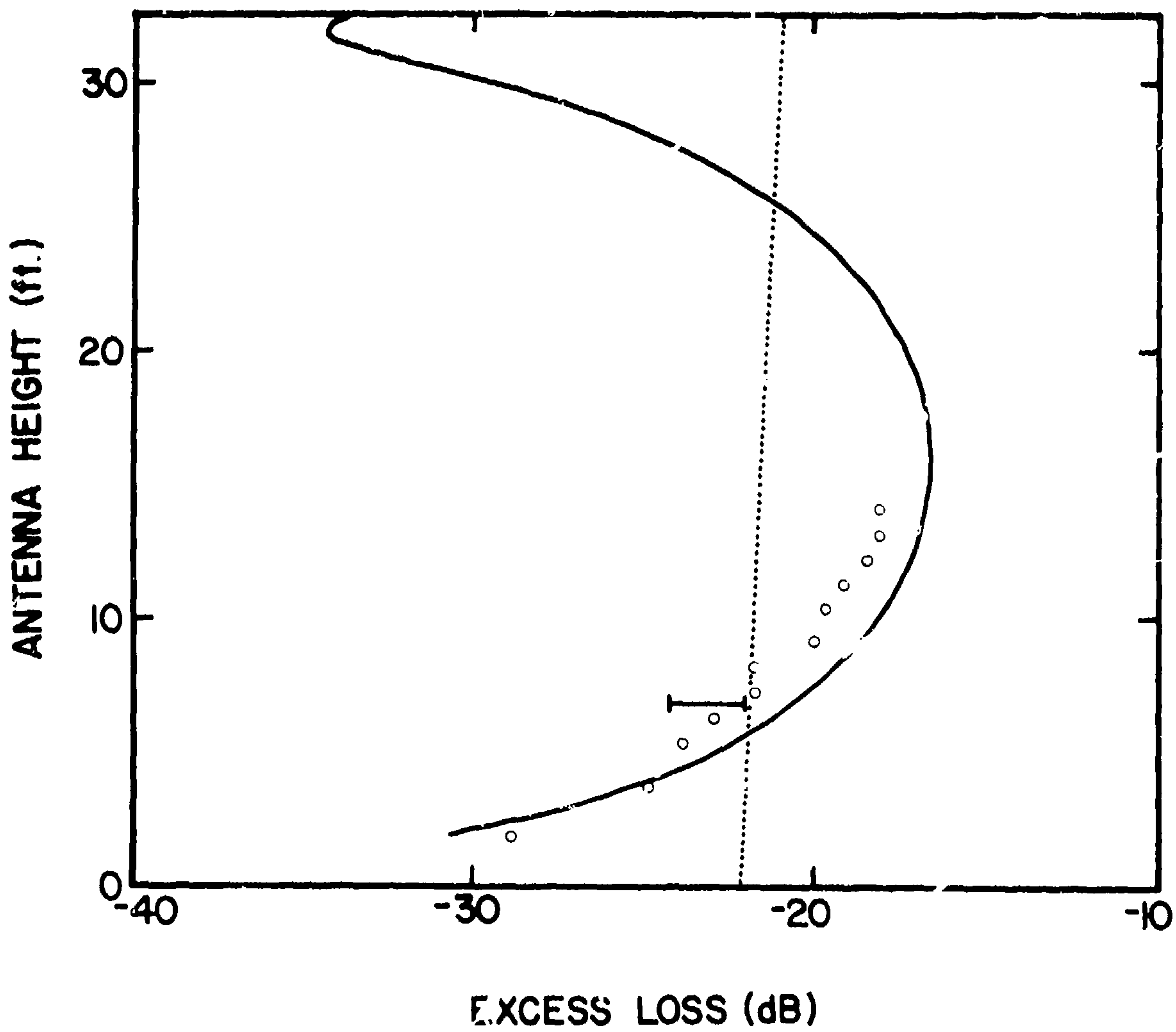

Fig. 10. Model Predictions of Excess Loss and Measurements at the Round Meadow Site. The dotted line shows the predictions for diffraction alone.

experiment as well as the experiment at Gardner airport, the Vogler computation agrees to within 0.1 dB with the Deygout calculation. The predicted curve in Fig. 10 deviates from the measurements by 2 dB at most.

The agreement between the measurements and the model calculations in Figs. 9 and 10 thus illustrates our ability to explain quantitatively the illumination of ground clutter by ground-based radars with a propagation model developed for aircraft flying at low altitudes. Further measurements will be necessary to obtain more detailed quantitative information about the influence of forests on low-altitude propagation, but these results will help in designing future ground-based experiments.

5.0 Conclusions

These measurements were made as the first step in an investigation of the effect of radar propagation on ground clutter. We made helicopter measurements primarily for the purpose of determining the magnitude of the product P_tAG in the equation

$$P_r = \frac{(P_tAG)F^2}{4\pi R^2}$$

where P_r and P_t are respectively the power transmitted and received over a one-way path, A is the effective aperture of

the receiving antenna, G is the gain of the transmitting antenna, R is the path length, and F the pattern-propagation factor. When this product is known from other measurements as is the case for operations with the Phase One Radar, then the ground measurements of F can be made without the helicopter.

Although very limited, these initial measurements illustrate the kind of information that can be obtained from ground-level propagation measurements. The agreement between the measurements and the model indicates that it is possible to model the propagation near the ground if the terrain profile including ground cover is accurately known. Measurements at several frequencies at each site should give valuable insight into the propagation factors that determine the frequency dependence of clutter on ground-based radars.

ACKNOWLEDGMENTS

The author is pleased to acknowledge the contributions of Louis S. DiPalma to this investigation. He designed and constructed the antenna supports for the ground-based antenna and assisted in the field measurements.

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This report describes an investigation of the influence of VHF propagation effects on radar ground-clutter. Signal-strength measurements at a frequency of 110.6 MHz were made between 2 and 15 ft. above the ground at ranges of 2.2 and 8.8 miles from a ground-based transmitter. Model calculations for the two propagation paths agree with the measurements to within 2 dB or less.